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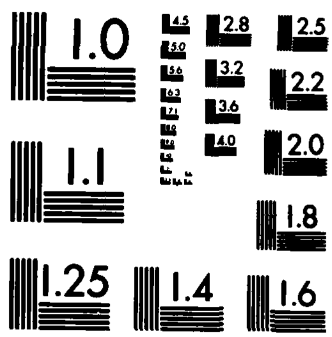

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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD ADVISORY REPORT No. 181

Propulsion and Energetics Panel Working Group 13 on Alternative Jet Engine Fuels

Volume 1: Executive Summary

NORTH ATLANTIC TREATY ORGANIZATION

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Volume I

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.181 – Volume I

PROPULSION AND ENERGETICS PANEL

WORKING GROUP 13

on

ALTERNATIVE JET ENGINE FUELS

Executive Summary

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This Advisory Report was prepared at the request of the Propulsion and Energetics Panel of AGARD.

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- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

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EXECUTIVE SUMMARY

1. INTRODUCTION

It is forecast that during the next twenty years the only economically available fuels for aircraft gas turbine engines will be those from the processing of conventional crude petroleum augmented by similar "synthetic" hydrocarbon components derived from other sources. This report therefore deals only with alternative fuels of this type which may entail considerable changes in fuel properties and relaxation of key items in present specifications to ensure adequate supplies.

Increasing fuel prices, growing demands for middle distillate fuels, including jet engine fuels, and growing difficulties with availability in most NATO Nations characterize the present situation in the aviation fuel market, both military and civil. This situation is likely to deteriorate considerably over the next twenty years. Only a limited amount of crude oil can be converted into aviation kerosine according to present specifications and there is also competition from other product requirements for this portion of the crude barrel. Conventional crudes are becoming heavier and synthetic crudes from tar sands, bitumen, very heavy crude oils, shale and eventually coal will be incorporated into refinery feedstocks. Broadening jet fuel specifications may be the only possible way of increasing the supply of fuel with reasonable economy in both refinery energy and cost. The physical properties as well as the hydrocarbon composition of the fuels would change and there is therefore an immediate need for the prediction of these properties and for research on their effects on handling and storage, aircraft fuel systems and engines.

These needs were recognized by the Propulsion and Energetics Panel and a series of meetings of interested panel members led to a recommendation to the Panel which in 1977 proposed a Working Group on Alternative Jet Engine Fuels with the following objectives:

- To bring together experts from all NATO Nations engaged in research and development work in the field of alternative jet engine fuels.
- To collect information on research and development programs, on their progress and results.
- To evaluate the results and impacts on the operation of aircraft engines and aircraft fuel systems.
- To identify gaps which need to be closed and to give pertinent recommendations for future research work.

The Panel also recommended that the Working Group should cover the following subject areas:

- Production methods for alternative aviation fuels with respect to fuel properties.
- Properties of alternative aviation fuels relevant to their use in military and civil engines and aircraft systems.
- Influence of alternative fuels on operation of existing engines and aircraft, i.e. performance and operational limits of present hardware systems using alternative fuels as well as modifications and adaptations that could be made to existing hardware systems.
- Application of alternative fuels in new aircraft engines, i.e. problems in combustors, turbines, and afterburners, and methods for their solution.
- Fuel system related problems including engine control and aircraft fuel systems, their impact on engine and aircraft operation, and methods for improvement.

The Working Group was approved by the National Delegates Board in March 1978. The work was divided into three tasks with Panel and non-Panel Members having required expertise assigned to each task group. The three areas were:

- Supply and demand scenarios for aviation turbine fuels in the NATO Nations for the next 20 years.
- The effects of projected quality fuels on current engines, new engines, and aircraft fuel systems.
- Guidelines for research fuels with properties representative of aviation turbine fuels to be expected in NATO Countries around the year 2000.

The following sections of this Report give a summary of the findings of the three Task Groups followed by general conclusions and recommendations. The detailed reports can be found in the Appendices of AGARD Advisory Report AR-181, Vol.II.

2. SUPPLY/DEMAND SITUATION

It is possible to examine the effect of changes in jet fuel properties on availability, energy consumption, and cost of refining by using refinery planning models. Such models are widely used by planners in the petroleum industry utilizing high speed computers to examine the role of new processes in meeting future product demands and to produce optimum solutions in terms of investments and operating costs. In the case of US civil jet fuel, NASA has contracted to examine five relaxations in product specifications to determine which produces the optimum solution in terms of availability and cost during the next thirty years.

There are many factors which are recognized to adversely affect future quality of all products produced from petroleum or alternative sources. These are discussed more fully in Appendix 1, but predominantly relate to the diminishing supply of high quality crude, the necessity to install processes to convert heavy fuels into lighter products, particularly distillates; and the requirement to meet a future demand pattern of less gasoline and more distillates including jet fuel.

In order to facilitate understanding of the relationships among various petroleum fuels which are discussed in the following sections of this report, Fig. 1 was prepared to show the approximate distillation limits of the major fuels produced from conventional crude. The limits are dictated by present specifications. It should be noted that NATO F-40 fuel (JP-4) contains a large proportion of gasoline fractions while NATO F-34 (JP-8) is a kerosine distillate similar to civil jet fuel. Other important distillates are diesel and burner fuels. Heavy fuel oils containing residual components are used mainly as boiler or furnace fuels or in large marine type diesel engines. The AGARD Research Fuel, described in detail in the next section and in Table 1, contains not only the F-34 area but also the hatched area which extends its distillation range into the higher boiling range of diesel fuel.

Analysis of products in refining planning studies requires the development of models which simulate by computer the real world of the petroleum refining industry. The types of models are largely determined by geography and marketing patterns. For example, in the US the crude supply and markets differ substantially between the West Coast and the remaining continental US area; these differences affect the type of models and crude inputs. In other NATO countries, similar differences exist, Western Canada differs from Eastern Canada, and Northern Europe from Southern Europe.

Markets in each area are supplied by refineries of varying complexity, depending primarily on historical product demand. For example, the high gasoline demand in the US has created many complex refineries that utilize reforming, catalytic cracking and various heavy fuel conversion processes. On the other hand, the higher fuel oil demand in Europe has emphasized less complex refineries that utilize primarily distillation and reforming. The model combination for each area must provide a different mixture of refineries of various complexities to match actual refineries to satisfy this product demand. The success of a model combination can be verified by comparing computer results with actual product outputs for a particular historical point. Verification is a critical step in model development.

The pattern of crude types and amounts are expected to change significantly during the next 30 years within the framework of overall energy requirements of NATO Nations. During this time period synthetic crudes produced from sources such as tar sands, bitumens, very heavy oils, oil shale and coal are expected to replace or supplement conventional petroleum as refining feedstocks. Each of these presents much more difficult refining problems and tends to make distillate products lower in hydrogen content (i.e. higher in aromatics and naphthalene) than conventional petroleum.

Demand for all products and their expected quality has a considerable influence on jet fuel. For example, dieselization of light trucks and automobiles will spur distillate demand at the expense of motor gasoline. The kerosine cut used for jet fuel is also a refinery blending stock for diesel and burner fuels. It has been suggested by a leading automobile manufacturer that to meet emission requirements, diesel for cars may have to be a light, low aromatic distillate even better than jet fuel. This proposal represents one of the uncertainties that would have to be addressed in computer studies using refinery models.

The quality of products such as cetane number of diesel fuel and sulphur content of burner fuels is controlled in modelling studies by including investment and operating costs for processes such as hydrogen treating and hydrogen generation. When variations in jet fuel quality are explored, the incremental refining costs including investments and return between one case and another are determined by a linear program as the computer seeks to balance the demand for all products vs jet fuel quality shifts for each combination of refinery models.

Although refinery modelling and linear programming studies can produce solutions to the economic vs quality questions sought, it should be recognized that any study involving a 30 year lookahead involves uncertainties. To list just a few of these:

(1) Will crude quality and supply follow the present downward trends or will new sources unexpectedly develop?

(2) Will the development of synthetic replacements for crude occur at the rate currently projected?

(3) Will present inflationary trends in energy cost continue to reduce demand for fuel oil and motor gasolines?

(4) Will US automotive diesel require high quality fuel better than jet fuel and degrade the remaining distillate fuel for aircraft use?

(5) Will the US Air Force and other NATO forces convert completely from JP-4 to JP-8 thus increasing demand on distillates?

A complete study for all NATO areas along the line of that presently being carried out for NASA for the US will be the subject of Working Group 16, approved in September 1981 to examine future supply and demand scenarios for aviation turbine fuels.

3. AGARD RESEARCH FUEL

There is a need for some guidance to aircraft, engine, and component manufacturers on the types and characteristics of aviation turbine fuel likely to be available in the year 2000 so that they can proceed with research work aimed at satisfactory operation on these fuels. It is possible from all the sources envisaged for the future to produce fuels meeting present specifications, but the cost and energy penalties for doing so are considered in most of the NATO Nations to be prohibitive. Therefore some deterioration in fuel properties seems inevitable and the efforts of fuel producers, equipment manufacturers, and fuel users will be required to establish the most economical and energy efficient route to be followed. In this context it was felt by the Working Group that the effort should be made to identify for AGARD a fuel to guide research activities. The properties included in Table 1, which define such an AGARD Research Fuel, represent a reasonable range based on present knowledge of expected fuel trends to the year 2000. These research fuel properties provide an envelope within which research in combustion, engine performance, fuel handling, etc. should be conducted.

The Working Group considered the possibility of including more gasoline fractions in an AGARD Research Fuel which would broaden the distillation range and dilute the effects of heavy ends and higher aromatics. However, more gasoline fraction would lower the flash point of F-34 below current specification levels and it was felt that such a fuel would be inconsistent with the present trend to convert military aircraft from F-40 to F-34 for safety and vulnerability reasons.

It is most important that, when expensive full-scale engine testing is undertaken, maximum benefit should be derived from the results by ensuring that the fuel properties are well documented so that they may be related to performance. In smaller scale studies on aircraft and engine components, combustion studies, experiments on spray formation, evaporation, ignition, blow-off, etc., it is equally important that the fuel characteristics be fully detailed to allow correlation with laboratory specification test methods and full scale trials.

Since relatively rapid developments are occurring in fuel sources, fuel processing, additives, etc., it is difficult to forecast the situation twenty years ahead and it is recommended that the AGARD Research Fuel property guidelines should be reviewed at regular intervals in the light of further developments.

It should be noted that reference to 'alternate' and 'emergency' fuels below does not imply that such fuels comply with the requirements of fuels currently so designated in other NATO publications. Rather an 'alternative' fuel in this report is one that could conceivably be a primary aviation fuel in the Year 2000, such as the AGARD Research Fuel, and an 'emergency' fuel is any not too closely related liquid fuel such as leaded gasoline or diesel fuel available at such time.

4. EFFECTS OF PROJECTED FUELS ON ENGINES AND FUEL SYSTEMS

A detailed assessment has been made on the effects of potential variations in hydrocarbon fuel properties on the performance, operating envelope, exhaust emissions, durability, maintainability, reliability, and safety of gas turbine aircraft. The assessment considered four specific subject areas affected by changes in fuel properties:

- Combustor Heat Transfer and Exhaust Pollutants
- Combustor Spray Formation, Evaporation, Ignition, and Blow-off
- Fuel Thermal Stability
- Fuel Flow Characteristics

Each subject area considered the fuel properties having the most significant influence on those particular design and operating criteria for gas turbine powered aircraft corresponding to the potential changes in fuel characteristics suggested by the AGARD Research Fuel. The fuel properties subject to change in the future having the greatest influence on gas turbine aircraft include: (1) hydrogen content (aromatics), (2) viscosity, (3) volatility, (4) storage and thermal stability, and (5) freezing point. The sensitivities of various components of gas turbine aircraft to variations in fuel properties and potential penalties in performance and durability are presented along with needs for advanced technology to counteract potential penalties in future aircraft.

4.1 Combustor Heat Transfer and Exhaust Pollutants

In the course of the study, a smoke emissions index correlation has been suggested which may allow extrapolation of existing data to fuels of lowered hydrogen content burning at increased combustor pressures, with some quantitative accuracy. Further, weight percent hydrogen appears to be the governing fuel property with respect to smoke emissions and flame radiation as long as naphthalene content remains at the current low level. However, recent data suggest that high naphthalene content may affect smoke and radiation, and should, therefore, be included in the correlation along with hydrogen.

Predictions of a linear wall temperature parameter, in terms of correlations developed over twenty years ago are surprisingly good in terms of the extrapolations in fuel property values. The exceptions here involve modern lean primary zone combustors, where the predictions are conservative. In either case, the increase in liner wall temperature with decreasing fuel hydrogen content can lead, particularly in low pressure ratio engines, to substantial decreases in liner durability. For example, the correlation which relates liner life to fuel hydrogen content predicts that durability would would be decreased by as much as 50 percent for a fuel hydrogen content decrease from 14.5 percent which is typical of present F-40 fuel to 13 percent for that of the AGARD Research Fuel.

Combustor data for gaseous emissions and combustion efficiency generally show only a small dependence on the various fuel properties, although at some increased viscosity level, finite droplet evaporation times will lead to increased idle emissions of carbon monoxide and unburned hydrocarbon, with a corresponding decrease in combustion efficiency. Oxides of nitrogen would tend to increase with fuels containing nitrogen compounds, but such fuels generally need to be denitrogenated to meet thermal stability requirements.

Further verification and development of the smoke emissions correlations is recommended and could result in reduction in the need for rig and engine testing, particularly at high combustor pressure levels with fuels difficult to obtain in quantity.

To provide reliable predictions of carbon in exhausts, it is recommended that a standard technique be developed. The measurement will involve isokinetic sampling and may require gravimetric determination.

It is recommended that careful experiments be conducted to determine effects of hydrocarbon structure (e.g. multi-ring aromatics) on carbon formation and flame radiation.

It is further recommended that heat transfer correlations be updated to include modern lean primary zone combustors. If the existing correlation is shown to apply to lean burning combustors, then it should be extended to fuels of low hydrogen content.

Continuing work is required to improve atomizer and primary zone combustor designs and film cooling techniques to protect liner walls. These measures would minimize the impact of decreased hydrogen content on liner durability.

4.2 Combustor Spray Formation, Evaporation, Ignition and Blow-off

The combined effect of increased viscosity and decreased volatility results in increased evaporation times and a considerably worsened ignition behaviour, particularly at low temperatures characteristic of cold starts and altitude relight. Blow-off characteristics of a combustor are influenced only slightly.

Viscosity and volatility are the main fuel properties which affect mixture formation in combustors – spray formation, droplet distribution, and evaporation – as well as ignition. Surface tension and liquid fuel density are of secondary importance. An increase in fuel viscosity leads to large drop size, the magnitude of which depends on the type of fuel injector used. For the maximum viscosity in the proposed AGARD Research Fuel, the Sauter mean diameter of fuel sprays from pressure swirl atomizers will increase by about 10 percent, from air blast atomizers by about 5 percent, while sprays from rotary injectors are insensitive to viscosity. To decrease the Sauter mean diameter of fuel droplets and to keep evaporation times at present levels, it is recommended that energy input for atomization be increased. This can be achieved either by air blast atomization or increasing the fuel supply pressure. An external air supply is needed if combustor pressure loss, and hence, engine performance is not to be compromised. This is true, in particular, for engine start-up at low ambient temperatures. For pressure swirl atomizers, the fuel pressure has to be increased by roughly 80–100 percent, which causes problems with weight penalties for the high pressure fuel system and nozzle size. However, pressure swirl atomization with spill return flow seems to offer a possibility for changing drop sizes independent from fuel mass flow.

It is recommended that experiments be conducted to define to what extent combustor hardware is sensitive to increased viscosity and decreased volatility of fuel. Improved fuel injectors and control procedures should be developed to minimize these effects.

It is further recommended that improved ignition devices should be developed which allow reliable ignition, in particular for cold starts and high altitude relight.

4.3 Fuel Thermal Stability

Thermal stressing and long term storage, particularly of the AGARD research type fuels, could lead to the production of fuel insoluble compounds. Higher pressure ratio engines and supersonic aircraft will exacerbate this situation through their inherently higher thermal loadings on the fuel system of both engine and aircraft. The presence and deposition of these insolubles within the fuel system, particularly in the atomizer, will lead to fuel maldistribution problems, which in turn will cause engine starting and relight difficulties, and excessive temperature scatter in the turbine section. Adherence of fuel degradation products on moving parts can also result in fuel system component malfunction and failure.

Deposition within the heat exchangers will also reduce engine life due to lowered cooling capabilities, so that engine lubricating oil temperatures may rise thereby affecting the bearings. Deposition within the combustor and subsequent spalling, as well as the fuel maldistribution described above, will both lead to increased smoke emissions and thus engine signatures.

In order to reduce these effects, a quantitative definition of factors influencing thermal stability is of great interest, for both aircraft and engine fuel systems with AGARD research type fuels. This requires the identification and definition of laboratory specification-type methods for evaluating fuel thermal stability in line with engine experience (which may require a 'rig' to act as an intermediate step between the engine and laboratory testing). In addition, a method for quantifying fuel storage stability may also be required if the thermal stability tests do not continue to assure adequate storage stability.

It is further recommended that methods be sought to improve the thermal stability of the fuel by refinery processing and additives. Also, improved design and location of fuel system components should be investigated to minimize heat input problems and reduce the vulnerability to deposits.

4.4 Fuel Flow Characteristics

The major problem associated with flow behaviour and pumpability within aircraft fuel systems at low temperatures is the potential blockage of flow passages or 'hold-up' of fuel as a result of increasing freezing point. Analytical and experimental data indicate that long-range commercial aircraft may reach fuel tank temperatures as low as $-43°C$. Certain long duration military missions may experience even lower tank temperatures. For commercial aircraft, allowing for a $3°C$ margin of safety, a fuel with a freezing point greater than $-46°C$ might require some form of inflight fuel heating to avoid corrective flight manoeuvres that lead to increased fuel consumption. Short-range aircraft may be able to use fuels with higher freezing points without the use of inflight heating or, at most, through the use of ground pre-heating. Recent analytical and experimental research programs have studied the pumpability of higher freezing point fuels under simulated flight conditions both in unheated and heated fuel systems. Experimental studies of low-temperature fuel system behaviour should continue in small scale, and eventually, in full-scale installations to evaluate advanced methods for fuel heating and wing tank insulation. Additives such as pour point depressants should be explored to determine the feasibility and limits of two-phase flow for fuels near the freezing point. This research should be supported by fundamental research addressed to the development of improved correlations relating freezing point and viscosity to the chemical composition of non-ideal multi-component hydrocarbon fuel mixtures. Other fuel system research should be devoted to the study of the effects of potential changes in fuel properties on lubricity, material compatibility, aircraft safety, and system cleanliness.

4.5 Alternative Fuels in Existing Engines and Aircraft

The above analysis describing the sensitivity of aircraft fuel systems to fuel properties suggests that existing aircraft and engines are likely to have difficulties in operating successfully on an alternative fuel that approaches AGARD Research Fuel in properties. Engines might prove more difficult to start and to relight, exhaust smoke is likely to increase, and temperature patterns in the turbine section may show rapid deterioration. Aircraft scheduled for long duration flights might require flight diversions.

On the other hand, successful research using AGARD Research Fuel could show how to overcome operating difficulties with new engines and existing engines retrofitted with improved combustors and fuel systems. Whether a retrofit of existing systems or the installation of new engines is the more cost effective path to follow cannot be answered without the research suggested by this analysis.

5. CONCLUSIONS AND RECOMMENDATIONS

Increasing shortages of crude feedstocks and the threat of disruptions in supply caused by world economic and potential international conflicts may require a broadening of current jet fuel specifications to improve availability and to allow, at minimum cost and maximum energy efficiency, the use of feedstocks from alternative sources including heavy petroleum crudes, tar sands, coal liquids, and oil shale. To prepare for an uncertain future in jet fuel quality and availability, research is needed to more fully understand the effects of varying fuel properties on engine and aircraft fuel system performance, reliability, and durability, and to build the technology base that would allow greater fuel flexibility in future aircraft.

Since current production engines will still be in service at the turn of the century, research and advanced technology to accommodate possible future fuels must include cost effective retrofit options for current production aircraft as well as new engine and aircraft fuel systems. The following conclusions can be drawn concerning the impact on performance of operating current aircraft on an AGARD research type fuel:

- *Smoke emissions* and *flame radiation* are controlled principally by fuel hydrogen content.
- Hydrogen content thus has a major affect on *liner durability*. Calculations show that reductions in hydrogen content from 14.5% typical of F-40 fuel to 13% could lead to as much as a 50% reduction in current liner life although the implication of this prediction on maintainability depends on the engine system.
- *Low-temperature ignition* under cold start and altitude relight conditions will be degraded by increased viscosity and decreased volatility expected in future fuels unless evaporation times can be maintained at present levels by improved atomization. Present atomizers do not appear capable of this requirement.
- Fuels of inadequate thermal stability form *carbonaceous deposits* on fuel system hot surfaces resulting in both fuel system malfunctioning and possible fuel maldistribution and poor temperature patterns in the engine hot section. Future fuels of lower hydrogen content and decreased volatility tend to exhibit lower thermal stability.
- Fuel *pumpability* will be a problem for long duration flights with the higher freeze point temperatures typical of AGARD research type fuels.

Finally, the Working Group recommends that:

- Supply and demand analyses be conducted to assess the trends in military and commercial aviation fuel usage and refinery product yields, energy consumption, and costs; and furthermore the fuels outlook be reassessed periodically to keep abreast of rapidly changing refinery product demands and processing capabilities. The first such analyses will be the product of Working Group 16.
- Research programs such as those described in this report be aggressively pursued among AGARD member nations to determine the effects of fuel property variations on current service and future engines and aircraft fuel systems, and to develop and demonstrate advanced combustor and fuel system technology to accommodate poorer quality fuels likely to be encountered in the future.
- The AGARD Research Fuel, defined in this report, be adopted as a baseline fuel to ensure a consistent data base among participating researchers. Research programs should include, but not be limited to this AGARD Research Fuel, and a complete fuel property analysis should be performed and documented when reporting research results.
- Fuels research focusing on property and combustion characterization be conducted which relates chemical properties inherent in fuels from alternative sources to physical properties (both specified and unspecified), and finally to engine performance and durability.

TABLE 1

Properties of AGARD Aviation Turbine Fuels

Type	*Wide-Cut*		*Kerosine*		
NATO Code	*F-40*		*F-34, F-35*		*Proposed*
	Spec Limit	*Typical Values*	*Spec Limit*	*Typical Values*	*Test Fuel ARF (1)*
Composition					
Acidity, total (mg KOH/g), max.	0.015	0.006	0.015	0.004	(0.015)
Aromatics (% vol), max.	25.0	11.4	25.0	17.2	R
Olefins (% vol), max.	5.0	0.8	5.0	1.5	R
Sulfur, total (% mass), max.	0.40	0.042	0.30	0.048	(0.30)
Sulfur, mercaptan (% mass), max.	0.001	0.0005	0.001	0.0003	R
Hydrogen content (% mass), min.	13.6	14.4	13.5	13.8	13.2 ± 0.2
Volatility					
Distillation, IBP, °C	R	59	R	166	–
10% recovered at °C, max.	R	94	205	183	205
End point °C, max.	270	237	300	253	–
Flash point, °C, min.	–	–	38	52	(38)
Density at 15°C (Kg/L), min.	0.751	.763	.755	.804	R
Density at 15°C, max.	0.802		.840		
Fluidity					
Freezing point, °C, max.	−58	−62	−50	−54	−30
Viscosity at −20°C, cs, max.	–	–	8.0	4.3	12.0
Combustion					
Specific energy, net (KJ/g), min.	42.8	45.5	42.8	43.2	R
Smoke point, mm, min.	20.0	27.6	19.0	23.9	R
Naphthalenes (% vol)	–	–	–	1.86	R
Corrosion					
Copper strip, 2 hr at 100°C, max.	1b	1a	1b	1a	(1b)
Thermal Stability					
Maximum tube temp., °C	260	>260	260	>260	230
Contaminants					
Existent gum (mg/100 ml), max.	7.0	0.8	7.0	0.9	(7.0)
Water reaction interface, max.	1b	1b	1b	1b	(1b)
Water separation index (mod.) with/ without corrosion inhibitor, min.	70/85	90	70/85	94	(70/85)
Conductivity					
(pS/m), min.	200	–	200	–	(200)
max.	600		600		(600)

(1) ARF represents AGARD Research Fuel with properties defined by Propulsion and Energetics Panel Working Group 13. Values marked R are considered to be limited by other specification requirements and should be reported. Values in parenthesis are carried over from NATO F-34 to maintain SO_2 emissions, corrosion or contaminants at present levels.

(2) JFTOT at specified max. tube temperature requires a maximum pressure differential of 25 mm Hg and a maximum Tube Deposit Rating, Spun, of 17 (or less than Code 3 Visual Rating).

DISTILLATION RANGE OF MAJOR FUEL PRODUCTS

(Typical Initial and Final Boiling Points)

ARF = AGARD RESEARCH FUEL

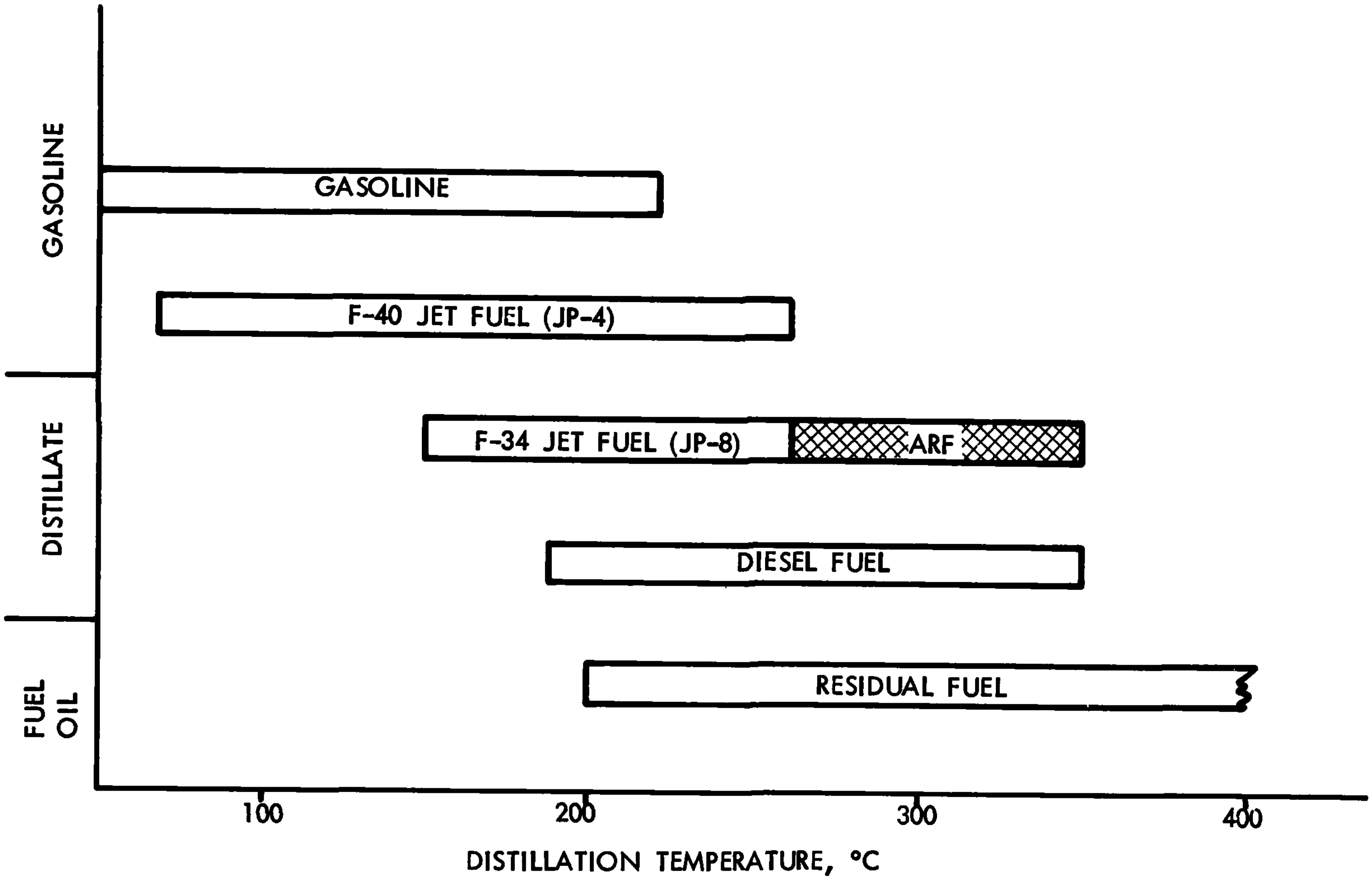

Figure 1

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* Retired from Panel and Working Group activities during this study.

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14. Abstract

The Propulsion and Energetics Panel set up Working Group 13 on 'Alternative Jet Engine Fuels' in 1978 to investigate possible properties of future civil and military aviation fuels and their effects on existing and new jet engines. This report discusses the supply and demand situation for kerosine type fuels, suggests properties of an AGARD Research Fuel for future experimental work, and discusses the probable effects of this kind of fuel on present and future engines. Some conclusions have been drawn based on present knowledge and areas requiring further research have been highlighted.

This Advisory Report was prepared at the request of the Propulsion and Energetics Panel of AGARD.

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